Site Characterization Evaluation of the Carbon TerraVault 26R Class VI Permit Application

This geologic site characterization evaluation report for the proposed Carbon TerraVault (CTV)-Elk Hills 26R Class VI geologic sequestration (GS) project summarizes EPA's evaluation of the geologic narrative submitted as part of CTV's Class VI permit application (dated November 5, 2021). This review also identifies preliminary questions for the applicant. Where specific information is lacking based on the currently available information, this evaluation identifies testing objectives that EPA recommends be incorporated into the Pre-Operational Testing Plan.

Regional Geology and Geologic Structure

The planned project is in the Elk Hills Oil Field (EHOF), in Kern County, California, in the southern San Joaquin Basin. CTV plans to inject CO_2 into the Monterey Formation over a period of 26 years via four injection wells, including one existing well (373-35R) and three wells that are to be constructed. Based on Figure 12 of the AoR and Corrective Action Plan (AoR CA), the three proposed wells lie to the northwest and southeast of 373-35R, extending over a range of approximately 3 miles. The 4 injection wells will inject into the Monterey Formation 26R reservoir at the 31S anticline at a depth of approximately 6,000 ft (Figure 8; pg. 4).

The Monterey Formation at the EHOF also contains the Miocene Reef Ridge Shale (the primary confining zone), which directly overlies the Monterey 26R injection zone and has been an effective seal for 40+ years of oil and gas operations (pg. 9). Figures 4 and 5 show the spatial distribution of wells in the EHOF and data available for use in characterizing the injection zone.

The Monterey 26R consists of turbidite sands bounded above and below by siliceous shale (pg. 8). The application asserts that this depositional history has resulted in minimal lateral communication of the Monterey 26 outside the EHOF (Figure 3; pg. 8). The reservoir is continuous across the area of review (AoR), then pinches out up-dip and on the channel edges (pg. 9). The pinch outs appear to coincide with the northwestern and southeastern edges of the delineated AoR (Figure 5).

The Tulare Formation consists of poorly consolidated sandstone, conglomerate, and claystone beds, which are exposed at intervals along the west border of the San Joaquin Valley (pg. 6). It is divided into the Upper Tulare and the Lower Tulare by the Amnicola Clay (a low permeability claystone). An aquifer exemption was approved for the Lower Tulare Formation within the Elk Hills Oil Field in 2018. The application describes the Upper Tulare Formation as an unsaturated air sand that is not considered to be an underground source of drinking water (USDW).

In addition to the Reef Ridge Shale, the Monterey 26R Reservoir is separated from the Upper Tulare Formation by the Amnicola Clay, the Lower Tulare Formation, the San Joaquin Formation, a depleted gas reservoir directly underlying the Tulare Formation, and the Etchegoin Formation (pg. 7, 27).

Tests and logs that were previously performed on the 373-35R injection well include: deviation checks, cement bond logs, open-hole well logs, a mechanical integrity test (MIT), standard annulus pressure test (SAPT), injection zone and confining layer coring, reservoir conditions and fluid checks, injection zone and confining layer fracture gradients, and pressure testing (Pre-Operational Testing Plan, Table 1).

Questions/Requests for the Applicant:

- *Is there a lower confining zone? If so, please describe it in the permit application narrative.*
- *In future updates to the permit application narrative, please label the injection wells on the maps (e.g., on Figure 2) to provide situational context.*
- *Which wells in Figure 4 contain data from the Reef Ridge Shale? Please elaborate on the characteristics of the Reef Ridge Shale, citing available well-specific data.*
- *Was any data collected during the logging and testing performed during drilling of the 373-35R injection well? If so, please characterize this data.*
- *Several of the figures in the narrative that contain data are difficult to read (e.g., Figures 14 and 27); please provide higher resolution versions of this information.*
- *Please provide a map of the Elk Hills Oil Field that shows the 373-35R well, the three proposed new injectors for the Elk Hills 26R storage project, and the 355-7R and 357-7R injection wells for the Elk Hills A1-A2 Project (with a scale that shows distances).*
- *Approximately how far apart will the four injection wells be from each other?*

Objectives for Pre-Operational Testing:

- *If no pressure build-up test results exist for the 373-35R injection well, perform pressure build-up testing as part of the Pre-Operational Testing Plan.*

Faults and Fractures

The 31S anticline and adjacent Northwest Stevens (NWS) anticline in the EHOF are separated by mid-Miocene thrust faults, which are described on pg. 10 of the narrative. The application states that the Reef Ridge Shale and Monterey Formation are well resolved based on seismic data, and there is no evidence of faults penetrating the Reef Ridge Shale or transecting the Monterey Formation. Figure 9 shows reverse faults in seismic profiles; however, the formations are not labeled. These reverse faults, oriented NW-SE, offset the anticline.

Evidence for confinement includes 3D seismic and well data confirming the absence of faults penetrating the Reef Ridge Shale, 40+ years of previous waterflooding and gas injection operation and geochemical analysis of 66 oil samples (Zumberge, 2005; Figure 11).

Questions/Requests for the Applicant:

- *Please update Figure 9 to label the formations in which the thrust faults terminate and the upper and lower extents of these formations.*
- *The application (e.g., on pg. 10 and 32) refers to the 26R anticline. Is this the same anticline as the 31S anticline? If so, please clarify the application.*
- *Please elaborate on the findings of the 2019 3D seismic survey described on pg. 10 and the evidence that there are no faults that transect the Monterey Formation or penetrate into the lower Reef Ridge Shale.*
- *Where were the 66 oil samples collected within the EHOF described on pg. 12 relative to faults within the field? Is any geochemical data available to support the discussion of geochemical analyses on page 12?*

Objectives for Pre-Operational Testing:

- *Collect pressure data in the Etchegoin Formation to support upward confinement between the Monterey Formation and shallower formations.*

Depth, Areal Extent, and Thickness of the Injection and Confining Zones

At the location of the injection wells, the stratigraphic sequence from top to bottom consists of the Tulare Formation, the San Joaquin and Etchegoin Formations, the Reef Ridge Shale confining zone, and the Monterey Formation injection zone (pg. 4, Figure 6). The depths and thicknesses of the injection and confining zones were determined based on wireline logs.

The table below summarizes the depth and thickness of the formations of interest according to available data in the permit application narrative. Some depth/thickness information for the San Joaquin or Etchegoin Formations was not provided; however, this is not critical for the purposes of the application evaluation. Porosity and permeability data are also presented in the table below; additional discussion of these characteristics is provided under "Geomechanical and Petrophysical Characterization."

Unit	**Average Depth within the AoR**	**Thickness Across the AoR**	**Porosity**	**Permeability**
Tulare Formation	900-1,000 ft (pg. 26)	900-1,000 ft (pg. 26)	34-40% (pg. 6)	1,410-8,150 mD (pg. 6)
San Joaquin Formation	Not given	Not given	28%-45% (pg. 7)	64-6,810 mD (pg. 7)
Etchegoin Formation	1,500-4,000 ft (pg. 7)	Not given	29-37% (pg. 7)	32-826 mD (pg. 7)
Reef Ridge Shale (Confining Zone)	4,084 ft-5,949 ft TVD (Table 1); 5,000 ft TVD (pg. 8)	1,000 ft (pg. 11) 640-1,598 ft (Table 1); 750-1,600 ft (pg. 8); 800-1,000 ft (pg. 32); 800+ ft (Fig. 10)	7.7% (pg. 17); 7% (pg. 8); 4 to 14% (Table 2)	<0.01 mD (pg. 8, 32); 0.0084 mD (pg. 17); 0.00003 to 0.0917 mD (Table 2)
Monterey Formation 26R Reservoir (Injection Zone)	4,828 – 7,827 ft mean = 6,014 ft TVD (Table 1); 6,000 ft (pg. 8)	255-2,497 ft; mean = 1,283 ft. (Table 1)	20%-30%, mean 24% (pg. 16, Figure 16); 25% (pg. 8)	3-1,500 mD (pg. 16, Figure 16); 45 mD (pg. 8)

Questions/Requests for the Applicant:

- *There is a typo on Figure 15, "Capitally" for Mercury Injection Capillary* Pressure. Please fix this when the application is updated.
- *Please characterize, name, and provide depth and permeability data for the underlying confining unit, if one exists.*

Hydrologic and Hydrogeologic Information

The Lower Tulare Formation, which overlies the San Joaquin Formation, was approved as an exempt aquifer in 2018 (pg. 6). The regional extent of the exempted portions of the Lower Tulare Formation is shown in Figures 6 and 24. It extends well beyond the AoR in the southern direction but closely borders the AoR to the north. Figure 26 is a type log from Well 1CH-27R, located just outside of the AoR to the southwest, which shows the depth to the Upper Tulare. The application states that the Upper Tulare Formation is unsaturated in the area of the 26R wells; thus, no USDWs are described in the AoR of the project. However, the permit application package refers to the presence of a USDW in several places: page 7 of the narrative refers to the "Upper Tulare USDW," and there is reference to a USDW on pg. 6 of the Testing and Monitoring Plan. No information is provided to support the unsaturated nature of the Upper Tulare Formation or a determination that it is not a USDW.

The San Joaquin Basin has no appreciable surface or subsurface outflow (pg. 28). The primary source of surface water and fresh groundwater is the Kern River, which drains to the southeast and terminates near the EHOF (pg. 28). Low precipitation rates and high evaporation rates result in almost no groundwater recharge from precipitation, leading to high salinity and TDS concentrations (pg. 29). CTV did not find any water supply wells within the AoR in a search of CALGEM, USGS, Kern County Water Agency (KCWA), West Kern Water District, and the GeoTracker Groundwater Ambient Monitoring and Assessment online database (pg. 29). CTV owns the surface area of the EHOF (pg. 29).

Questions/Requests for the Applicant:

- *Please provide evidence to explain why CTV does not consider the Upper Tulare Formation to be a USDW within the modeled AoR of the 26R Project injection wells.*
- *It appears that Figure 24 provides information on the depth and regional extent of the area shown in cross section with wireline logs for TDS content, however the resolution is low. Please provide a higher resolution version of Figure 24.*
- *What is the depth of the Upper Tulare Formation and its separation from the injection zone and the confining zone within the AoR in the vicinity of the 26R project wells?*
- *Is a boring log available for Well 1CH-27R with lithology, water level, or water quality parameters to provide additional information about the Tulare Formation?*
- *Several of the references to Figures 24-28 in the section on "Hydrologic and Hydrogeologic Information" (pg. 26-28) are incorrect. Please revise the narrative text.*

Geochemistry/Geochemical Data

Limited baseline geochemical data for the Upper Tulare Formation and Monterey Formation (injection zone) are provided in the application.

Figure 27 shows the results of water analysis performed on waters from the Upper and Lower Tulare Formations. Figure 27 is difficult to read, but it appears that the analysis is from 1995, and the analytes include some, but not all, of those planned as part of injection and post-injection phase monitoring. The TDS values of the Upper Tulare Formation appear to be 4,800-4,900 mg/L.

The application states that geochemical water analysis for the 26R Monterey Formation reservoir has been performed across the AoR as part of routine surveillance since reservoir discovery (pg. 30). Figure 28 presents Monterey Formation 26R reservoir water geochemistry from well 317-26R, which is located just outside of the southwestern edge of the AoR. No TDS data are provided, but a measurement of "equivalent salt" of 23,944 ppm is shown; thus, it appears that the Monterey Formation is not a USDW. CTV also provides hydrocarbon composition for well 356-26R (Figure 29), which the application states is within the AoR, although it is unclear where the well is. However, no water quality data on this well is presented.

CTV's Testing and Monitoring Plan (Attachment C) includes monitoring the overlying Etchegoin Formation and the Tulare Formation for groundwater quality and geochemical changes and the Monterey Formation as part of direct plume tracking activities. Water quality will need to be established in each of these formations prior to injection operations to provide a baseline for comparison to future monitoring results.

Questions/Requests for the Applicant:

- *Where is Well 356-26R, the source of hydrocarbon geochemistry in the Monterey Formation, and is any water quality (i.e., TDS) data available from this well? If so, please provide this.*
- *Please provide any additional Monterey Formation water quality data that was collected as part of the "routine surveillance" described on page 31 to support a more thorough understanding of the formation's water quality throughout the AoR and to support a determination that the Monterey Formation is not a USDW.*
- *Is any water quality data available for the Etchegoin Formation? If so, please provide this.*

Objectives for Pre-Operational Testing:

- *Establish baseline geochemistry for the Monterey Formation in the vicinity of the 26R project wells, as well as the Tulare and Etchegoin Formations for all analytes to be monitored during injection operations, per the Testing and Monitoring Plan.*

Geomechanical and Petrophysical Characterization

Compressional sonic data from 11 wells within the AoR, with 22,592 individual logging data points, show that the average ductility of the confining zone is 1.59. A brittleness calculation methodology from Ingram and Urai (1999) and Ingram et al. (1997) determines that the average rock strength of the confining zone is 2,385 psi (pg. 19). From this value, the brittleness of the confining zone was found to be less than 2. The applicant concludes that a brittleness value of less than 2 is evidence that the confining layer is sufficiently ductile to anneal discontinuities and that there are no fractures for fluid migration (pg. 20; Figure 18). The application states that this conclusion is further supported by historical water and gas injection data at the site, in addition to millions of years of confinement of oil and gas in the Monterey Formation by the Reef Ridge Shale (pg. 20).

In the EHOF, the maximum principal stress direction is northeast-southwest as determined by a study of EHOF fracture gradients and borehole breakout (Castillo, 1997; Figure 19). Table 3 of the application narrative is reproduced below.

Stress	Reef Ridge Confining Layer	Monterey Formation
Pore Pressure Gradient (psi/foot)	0.433	0.5
Overburden Gradient (psi/foot)	0.91	0.92
Breakdown Gradient (psi/foot)	1.12	1.03

The GEOMECH geomechanical model, along with the GEM equation of state compositional reservoir simulator, were used to determine failure pressures under a base case and three additional scenarios;

this modeling is described on pages 21-23 of the application narrative. Descriptions of variations from the base case for other scenarios are given below:

- Reduced Young's Modulus: to model uncertainty in the cap rock Young's Modulus, a second case was run with a value of 8E05 psi.
- Reduced Injection Rate: sensitivity to injection rate was studied by reducing the injection rate to 20 mmscfd.
- Thinner cap rock: the impact of a thinner cap rock was modeled by assigning a confining layer of 795 feet.

Table 4 of the application narrative, which presents the results of the geomechanical modeling, is reproduced below:

Geomechanical Scenario Results	
Scenario	**Failure pressure (psi)**
Base Case	8,306
Reduced Young's Modulus	8,388
Reduced Injection Rate	8,340
Thinner Cap Rock	7,600

Figure 21 shows the change in normal fracture effective stress in the bottom cap rock layer and the pressure in the top layer of the reservoir with time for each scenario. See also the evaluation of the AoR CA (Attachment B) for additional information.

Porosity and Permeability

Capillary pressure in the Reef Ridge confining zone was determined to be 4,220 psi using mercury injection capillary pressure (MICP) analysis on 11 core data points from well 355X-30R (Table 2; Figure 17). Well 355X-30R is outside of the AoR for the CTV 26R project, to the south. As shown in the table under "Depth, Areal Extent, and Thickness of the Injection and Confining Zones," above, porosity values for the Reef Ridge Shale are approximately 7-14%, and reported porosities of the Monterey 26R Reservoir range from 20%-30%. The permeability of the Reef Ridge Shale is about 0.01 mD, and Monterey Formation permeability ranges from 3-1,500 mD. Permeability and porosity for the Reef Ridge Shale in the 355X-30R well are presented in Table 2 of the application. Figure 4 shows the locations of wells with core MICP permeability data and, while the locations are difficult to discern due to the quality of the image, they appear to represent the entire AoR.

Formation porosity and permeability used as inputs for the geomodel were determined using wireline log data, including SP logs, gamma ray, borehole caliper, resistivity, neutron porosity, and bulk density (pg. 15). Porosity is determined from bulk density using a 2.65 g/cc matrix density calibrated from particle density (Figure 15) and porosity data. Clay volume is determined from neutron-density separation and is calibrated to core data. A permeability function was calculated using MICP porosity and clay values, and is presented in Figure 15. The application states (on pg. 15) that core data from 13 wells with 175 data points were used to calibrate log porosity and to develop a permeability transform. However, it is unclear which wells are the source of this data.

Questions/Requests for the Applicant:

- *Where is the well that is the source of the data in Table 3?*
- *Given that well 355X-30R, the source of the Reef Ridge Shale porosity/permeability data, is outside of the AoR, please explain how this data is representative of the confining zone throughout the AoR of the 26R project.*
- *Please provide Monterey Formation and/or Reef Ridge Shale permeability data from some of the wells depicted on Figure 4 to support a more thorough characterization of the formations throughout the AoR.*
- *Please discuss the selection of the base case parameter values (i.e., Young's Modulus, thickness, etc.) in the geomechanical modeling.*
- *Please update Figure 21 to include the base case pressure.*
- *The application references core data from 13 wells on page 15.*
    - *To which wells does this refer and where are they located?*
    - *If they are not distributed throughout the AoR of the 26R project, please describe how they are representative of the entire area that will be affected by injection.*
- *Where are the 11 wells that are the source of ductility data discussed on pg. 20 located?*
- *Does reference to the "GEOME0.CH" geomechanical model on pg. 21 contain a typo? If so, please correct this.*
- *Laterally, the wells with MICP core data are concentrated around the northern end of the 31S structure. Is any MICP core data available from wells on the southern end of the 31S anticline?*
- *The application states that, "The final/maximum values for surface and downhole injection pressures are far below those associated with the Class II permitted fracture gradients of .8 psi/foot," and that, "the final reservoir pressure target of 3,250 PSI is significantly below the Reef Ridge confining shale estimated minimum geomechanical tensile failure pressure of ~7,500 PSI" (pg. 38). Please clarify the sources of data used to determine failure pressure, fracture pressure, and fracture gradient.*

Objectives for Pre-Operational Testing:

- *Determine the porosity and permeability of the Reef Ridge Shale at the location of each of the 26R project wells.*

Mineralogy of the Injection and Confining Zones

X-ray diffraction (XRD) data from 108 data points in 9 wells was analyzed to determine injection zone mineralogy, and Fourier Transform Infrared Spectroscopy from 36 points in 1 well located outside the AoR but within the EHOF was used to characterize confining zone mineralogy (pg. 14). Figure 13 presents Monterey Formation 26R sand mineralogy from well 377H-26R, which is located within the AoR. The applicant addresses the use of a single well for characterizing the mineralogy of the confining zone, citing that it is representative of the formation because of depositional continuity and consistency of facies and properties within the EHOF.

The Monterey 26R intervals consist of 39% quartz, 49% potassium feldspar, albite, and oligoclase and 12% total clay. The Reef Ridge Shale consists of 47.1% silica polymorphs (Opal-CT, chert, and cristobalite), 29.5% total clay, 14.5% potassium feldspar, albite, and oligoclase, and 3.7% quartz (pg. 14).

Questions/Requests for the Applicant:

- *Please provide a map showing the locations of the 9 wells used as the source for XRD and the well that was the source for Fourier Transform Infrared Spectroscopy described on page 14.*
- *What evidence is there for depositional continuity and facies consistency within the EHOF, as described on page 14?*

Seismic History and Seismic Risk

Seismic history is discussed on pg. 24 of the permit application narrative. The application notes that the "EHOF is in a seismically active region, but no active faults have been identified by the State Geologist of the California Division of Mines and Geology (CDMG) for the Elk Hills area (DOE, 1997)." Seismic activity in the region stems from the San Andreas Fault (12 miles west of the project site) and the White Wolf fault (25 miles southeast of the site).

Regional seismic data dating back to 1932 was gathered from the Southern California Earthquake Data Center (SCEDC) and USGS databases. Figure 22 shows the eight (8) magnitude 5.0 or greater earthquakes that have occurred within a 30-mile radius of the EHOF. These earthquakes have an average depth of 6.3 miles, well below the Monterey Formation. The application states that there have been no earthquakes within the EHOF greater than magnitude 3.0. Site characteristics, including low factor amplification due to thin sediment, high density soil, and soft rock, based on shear-wave velocity (V_S) are asserted to further reduce seismic risk. The largest known earthquake in the region was a 7.5 magnitude 1952 earthquake in Kern County which did not affect reservoir containment. CTV does not describe plans to establish a baseline and assess natural and induced seismicity for the 26R project.

The evaluation of seismic risk also reflects other elements of the comprehensive permit application review (described elsewhere in this report), including porosity and permeability of the injection and confining zones; regional structural features; information on faults in the vicinity of the project site; formation pressure; and the geomechanical properties of the injection and confining zones.

Seismic risk and risk mitigation will also be considered in the review of the following aspects of the permit application:

- Predictions of plume and pressure front behavior over time, including pressure build-up over time, and pressure dissipation following cessation of injection.
- The ability of the injection well to maintain mechanical integrity under stress.
- Wells within the project area and the status of well corrective action.
- Planned injection pressures.
- Seismic monitoring and emergency and remedial response planning.

Questions/Requests for the Applicant:

- *Please include all earthquakes of magnitude 3.0 and above in Figure 22.*
- *The text on pg. 24 of the narrative refers to historical earthquake data in Figure 23; however this information is presented in Figure 22. Similarly, the text in point 2 on pg. 25 refers to the VS30 analysis of Figure 23 but references Figure 24. Please revise the text accordingly.*

- *To inform an evaluation and documentation that there is no significant seismic risk associated with the Class VI project, please describe how the project:*
    - *has a geologic system free of known faults and fractures and capable of receiving and containing the volumes of CO_2 proposed to be injected.*
    - *will be operated and monitored in a manner that will limit risk of endangerment to USDWs, including risks associated with induced seismic events;*
    - *will be operated and monitored in a way that, in the unlikely event of an induced event, risks will be quickly addressed and mitigated; and*
    - *poses a low risk of inducing a felt seismic event.*

Objectives for Pre-Operational Testing:

- *Establish baseline seismicity after the shallow borehole and surface seismometers (which are described in Attachment C) are installed.*

Surface Air and/or Soil Gas Monitoring Data

No soil gas or surface air data were submitted with the permit application. At this point, we do not believe this will be necessary; however, if the results of future reviews necessitate surface air and/or soil gas monitoring, we would request baseline data.

Facies Changes in the Injection or Confining Zones

The thicknesses and depths of the confining and injection zones are presented on structural and isopach maps based on 3D wireline log data (Figure 12). However, the locations and number of wells used to characterize formation depths was not provided.

Figure 3 of the permit application narrative shows a cross section of formations across the San Joaquin Basin, and Figures 5 and 6 show stratigraphic cross sections with well types for the 31S anticline. Figure 11 shows a stratigraphic column with oil samples grouped into families. There appear to be logs on the figure used to correlate the formations laterally, but they could not be distinguished.

Figure 4 identifies the wells that penetrate the Reef Ridge Shale and, per the cross sections in Figures 5 and 6, several wells have core data or logs within the Reef Ridge Shale and the Monterey Formation; however, it is unclear what information is available from the wells on the map and how it informed the application. The resolution of the cross sections (e.g., Figures 5, 6, and 24) is low, making it difficult to discern which wells contributed to development of the cross sections.

Page 32 of the application describes the development of a geo-cellular model as part of the Monterey 26R Formation reservoir characterization and plume modeling. The applicant asserts that the cross section in Figure 31, which appears to be an output of the AoR delineation model, demonstrates confinement of the injected CO_2 plume by up-dip pinch-out on the anticline structure and lateral confinement at the reservoir edges.

On page 9, the application concludes that the Monterey Formation 26R depositional framework and sand continuity have been established by static data that includes open-hole well logs and core data, as well as 3D seismic data. Discussion and questions for the applicant regarding lateral continuity of the Confining Zone are discussed above in the section on "Mineralogy of the Injection and Confining Zones."

Questions/Requests for the Applicant:

- *Please clarify what data sources were used to determine inputs for the geo-cellular model where applicable, e.g., the inputs for sand vs. shale reservoir facies as discussed on pg. 32.*
- *Please elaborate on how any well log data (e.g., from the wells shown on Figures 5 and 6) contributes to an understanding of the homogeneity of facies within the injection and confining zones.*
- *Please also discuss how a sufficient number and distribution of formation characterization data are available to demonstrate a lack of local heterogeneities that could affect CO_2 storage or confinement.*
- *Please clarify which wells are depicted on cross sections (e.g., Figures 5, 6, and 24), and if available, augment the narrative discussion with relevant log-derived evidence about the site.*
- *Please specify the names, number, and locations of wells that were used to characterize formation thicknesses for the maps in Figure 12.*

Objectives for Pre-Operational Testing:

- *Determine if there are any heterogeneities within the Monterey 26R Reservoir that could affect its suitability for injection, including facies changes that could facilitate preferential flow.*

Structure of the Injection and Confining Zones

Regional structure of the injection and confining zones is controlled by San Andreas Fault development resulting in mid-Miocene anticlines (pg. 3). The application describes the anticlines that form the Elk Hills Oil Field, which CTV asserts will contribute to confinement. See the discussions of "Regional Geology and Geologic Structure" and "Faults and Fractures," above.

CO_2 Stream Compatibility with Subsurface Fluids and Minerals

The proposed injectate will consist of at least 95% CO_2 with mixtures of water and oxygen that will be controlled for corrosion mitigation (pg. 38). The applicant states that corrosiveness of the stream will be "very low as long as the entrained water is kept in solution with the CO_2" which will be accomplished by limiting its water content (pg. 38).

The applicant states that existing subsurface fluid information is based on extensive and ongoing CO_2 injection activity in the EHOF region. The narrative also states that water saturations in the formation (34% saturation in the gas cap and 25% in the oil band) and low residual oil saturation (15-37%) will dissolve 20% of the injected CO_2. Furthermore, the Monterey 26R is dominated by quartz and feldspar, which are stable in the presence of CO_2 and carbonic acid (pg. 31).

The narrative states that there is no geochemical analysis of water samples from the Reef Ridge Shale because the shale will only provide fluid for analysis if stimulated (pg. 31). The CO_2 composition used for the geomodel and its interaction/solubility is established by the Peng-Robinson Equation of State (AoR and CA Plan, pg. 2).

Questions/Requests for the Applicant:

- *Please provide evidence for the statement on page 31 of the narrative that the quartz and feldspar in the Monterey Formation are stable in the presence of CO_2 and carbonic acid.*
- *Please elaborate on why use of the Peng-Robinson Equation of State supports compatibility of the CO_2 with any fluid that may be contained within the Reef Ridge Shale.*
- *The reference to the hydrocarbon analysis for Well 356-26R at the bottom of pg. 30 should refer to Figure 29, not Figure 30. Please revise the narrative.*

Objectives for Pre-Operational Testing:

- *Confirm the composition and water content of the CO_2 injectate as part of baseline sampling and provide verification (e.g., via benchtop studies or laboratory analyses) that it will not react with the formation matrix.*

Injection Zone Storage Capacity

Modeled storage capacity of the Monterey Formation 26R reservoir was up to 38 million tons of CO_2 (pg. 33). Table 8 (Proposed operational procedures) identifies this as the estimated maximum mass of CO_2 to be injected. This exceeds the total volume of CO_2 the applicant proposes to inject, as described in Table 5 of the AoR CA: 993 tons per day, which equates to 362,445 tons/year (or 9.4 million tons over the planned 26-year injection phase of the project), assuming continuous operation of the wells.

Injection zone storage capacity is also discussed above in the "Structure of the Injection Zone and Confining Zone" section, and will be discussed in the forthcoming evaluation of the AoR CA. Any additional follow up questions/requests for the applicant will be provided in the AoR modeling evaluation.

Confining Zone Integrity

Fluid confinement is supported by 3D seismic data (pg. 10) and historic operating experience. Core data (pg. 17) for the Reef Ridge Shale is based on data from well 355X-30R, which is outside of the AoR (see "Porosity and Permeability," above) and geochemical analysis (pg. 12). The capillary entry pressure of the Reef Ridge Shale is 4,220 psi in a CO_2-brine system, which, the application asserts, reduces the likelihood of deformation (pg. 17). There are no faults extending into the Reef Ridge Shale. See additional discussion and questions for the applicant above.

Questions/Requests for the Applicant:

- *Does any pressure data exist to provide evidence of pressure differentials that would demonstrate confinement between the Monterey 26R Formation and shallower formations? If none exists, please include characterizing the pressure in the Etchegoin Formation in the pre-operational testing plan.*
- *Please provide specific geochemical data that support the statement on pg. 11 of the narrative that, "Geochemical analysis of reservoirs within the EHOF also confirms compartmentalization through several million years and effectiveness of the Reef Ridge Shale to contain the CO_2 injectate."*

Objectives for Pre-Operational Testing:

- *Test for changes in capillary entry pressure of the Reef Ridge Shale due to reaction of the shale with the injectate via laboratory experiments.*
- *A step rate test should be performed to establish the fracture pressure of the confining zone.*